

**REMARKS**

**I. Status of Claims**

Claims 7-16 are currently pending. Claim 12 replaces cancelled claim 6. This amendment is supported by the specification, for example, at page 4, line 22 to page 5, line 9. New claims 13-16 have been added and are supported by the specification, for example, at page 4, line 22 to page 5, line 9. As suggested by the Examiner, Applicants amended claim 9 to correct the spelling of glycidylethers. This amendment is supported by the specification, for example, at page 7, line 29 to page 8, line 4. Applicants further amended claims 7, 8, and 10 to correct their dependency and remove redundant language (such as "optionally substituted"). This amendment is supported by the specification, for example, at page 5, line 11 to page 6, line 33. Applicants submit that no new matter has been added by these amendments.

**II. Specification Objections**

The Examiner objected to the use of the term "poly(perfluorocyclobutanes)" for the reasons disclosed at page 2 of the Office Action. Applicants respectfully disagree and submit that a person of ordinary skill in the art would understand the scope of the term, as written. In particular, a person of ordinary skill in the art would recognize that the term encompasses those polymers described in the patents cited at page 2, lines 22-23. Applicants further submit that term is proper as established by IUPAC A1.1. *Nomenclature for Homopolymers* (courtesy copy enclosed). Consequently, poly(perfluorocyclobutanes) is proper.

Further, Applicants have amended the specification to consistently refer to poly(perfluorocyclobutanes) as PFCBs.

Applicants submit that the currently amended specification obviates the Examiner's objections and respectfully request that the Examiner withdraw the objections to the specification.

**III. Claim Objection**

The Examiner objected to claims 6 and 9 for reasons disclosed at pages 2 of the Office Action. Claim 6 has been replaced by new claim 12. Applicants submit that currently amended claims 9 and 12 obviate the Examiner's objections of these claims and respectfully request that the Examiner withdraw the objections to claims 9 and 12.

**IV. Rejection Under 35 U.S.C. § 103(a)**

The Examiner has rejected claims 6-11 under 35 U.S.C. § 103(a) as obvious over U.S. Patent No. 5,246,782 ("Kennedy") in view of U.S. Patent No. 5,780,159 ("Bauer") for the reasons disclosed at pages 4-6 of the Office Action. Applicants respectfully traverses this rejection for at least the reasons presented below.

To establish a *prima facie* case of obviousness under 35 U.S.C. § 103, the Examiner bears the burden of establishing each of three requirements. First, the references must teach or suggest each and every element recited in the claims. See M.P.E.P. § 2143.03. Second, the Examiner must establish that some suggestion or motivation exists, either in the references themselves, or in the knowledge generally available to one of ordinary skill in the art, to combine the references to achieve the presently claimed invention. See M.P.E.P. § 2143.01. Third, the Examiner must establish a reasonable expectation of success for the proposed combination. See M.P.E.P. § 2143.02. Moreover, each of these requirements must "be found in the prior art, and not be based on applicant's disclosure." M.P.E.P. § 2143. At a minimum,

Applicants submit that the Examiner cannot establish that some suggestion or motivation exists, either in Kennedy or Bauer themselves, or in the knowledge generally available to one of ordinary skill in the art, to modify the references to achieve the presently claimed invention. See M.P.E.P. § 2143.01. Applicants further submit that the Examiner cannot establish a reasonable expectation of success from the proposed combination in view of the inherent uncertainties. See M.P.E.P. § 2143.02.

As noted in page 5 of the Office Action, the Examiner has admitted that Kennedy is silent regarding the use of “a second material selected from a polycyanate resin (co)polymerized from at least one difunctional cyanate.” In fact, Kennedy discloses an immense array of compounds, including wood, metal, ceramics, paper, and polymers. as its second material. '782 patent at col. 2, line 23-43. Kennedy teaches a preference for glass, metals, and polymers, including the extremely broad class of thermosets, without any selection rules to arrive at thermosets, let alone Applicants' recited species of polycyanates. Kennedy does not disclose the genus polycyanates or any species therein. Hence, the Examiner relies on Bauer.

The Examiner's factual findings regarding the motivation to combine or modify must be “clear and particular.” *In re Dembiczak*, 175 F.3d 994, 999 (Fed. Cir. 1999). Here, the Examiner argues on page 5, that Kennedy discloses the use of thermosetting crosslinkable polymers and claims that “one of ordinary skill in the art would have found it obvious to apply Bauer's polycyanates as the other polymer layer in the form of laminate as taught by Kennedy.” Applicants submit that the Examiner's argument is flawed because there is no motivation for a person of ordinary skill in the art to select thermosets, polycyanates, or even the recited polycyanates, based on

Kennedy's disclosure. In fact, the M.P.E.P. expressly explains that, "[t]he fact that a claimed species or subgenus is encompassed by a prior art genus is not sufficient by itself to establish a prima facie case of obviousness." M.P.E.P. § 2144.08 (*citing In re Baird*, 16 F.3d 380, 382 (Fed. Cir. 1994)). A person of ordinary skill in the art armed with the Kennedy reference has no basis to select the polycyanates of Applicant's invention. Applicants submit that Kennedy's disclosure does not even qualify as the disclosure of a genus that encompasses Applicants' recited polycyanates. A person of ordinary skill in the art knows that Kennedy's recital of "thermoset" is no more helpful than the recitation of "polymer." It is well known in the art that all polymers are divided into two classes of which thermoset is one. Pacific Northwest National Laboratory's *Materials Science and Technology Teacher Handbook: Polymers*, at 7.1. Accordingly, a person of ordinary skill in the art would not be motivated to select any polycyanate based on the disclosure of "polymer" let alone on the mere disclosure of "thermoset." See *in re Baird*, 16 F. 3d at 382. Consequently, the Examiner has failed to set forth such "clear and particular" evidence here.

*In re Baird* is analogous to the present facts and provides legal precedent for the patentability of Applicants' use of polycyanates over Kennedy's incredibly broad disclosure of thermosets. The invention in *Baird* covered a flash fusible toner comprising a polyester of bisphenol A and an aliphatic dicarboxylic acid. The Office asserted that the polyester in *Baird* was obvious in light of a prior art reference which specifically disclosed compositions comprising esters of three dicarboxylic acids claimed and a generic diphenol formula that encompassed bisphenol A. Although *Baird* argued that the reference lacked motivation to select bisphenol A, the Board disagreed,

concluding that the generic disclosure of the reference provided ample motivation to select the claimed bisphenol A polyester binder resin in arriving at the claimed composition. *Id.* at 1551.

The parties did not dispute that the generic diphenol formula of the cited reference encompassed the claimed species, bisphenol A. Further, Baird did not dispute that the reference specifically disclosed the three dicarboxylic acids recited in the appealed claim. *Id.*

Nonetheless, the Federal Circuit reversed the decision of the Board, holding that a generic formula does not by itself necessarily render a compound encompassed by that formula obvious. *Id.* at 1552. Noting that the generic formula of the diphenol contained a large number of variables, thus encompassing a large number of different diphenols, and “unquestionably encompass[ed] bisphenol A when specific variables are chosen, there is nothing in the disclosure of [the prior art reference] suggesting that one should select such variables.” *Id.* at 1552. (alterations in original). The court further observed that the reference appeared to teach away from using bisphenol A by focusing on other diphenols. *Id.* at 1552.

Emphasizing that one must evaluate a reference “not only for what it expressly teaches, but also for what it fairly suggests,” the Federal Circuit in *Baird* considered the vast number of diphenols encompassed by the generic diphenol of the reference, coupled with the clear preference for diphenols other than that claimed by Baird, and concluded that the prior art did “not teach or fairly suggest the selection of bisphenol A.” *Id.* at 1552. The court therefore determined that the Board clearly erred in holding Baird's claimed compound obvious under § 103.

Like *Baird*, where the genus “unquestionably encompassed” the Bisphenol A of the claims, the class of thermosets, recited by Kennedy unquestionably encompasses polycyanates just as the term “polymer” does. See *In re Baird*, 28 U.S.P.Q.2d at 1551. However, when Kennedy is considered as a whole, as was the reference in *Baird*, the fact that Applicants’ subgenus of polycyanates are within the scope of Kennedy’s thermosets is not enough to establish a *prima facie* case of obviousness for the same reasons provided in *Baird*.

First, like the reference in *Baird*, the class of thermosets encompasses a very large number of compounds defined by a broad range of substituents, of which 99.9% are not recited by Applicants’ pending claims. See *id.* at 1552. Second, like the reference in *Baird*, Kennedy fails to provide one skilled in the art with the motivation to select the polycyanates from the class of thermosets. See *id.* In fact, Kennedy provides no motivation to select the dicyanates of formula I as claimed by Applicants. Consequently, third, like the reference in *Baird*, Kennedy appears to even teach away from the suggested modifications through its disclosure of irrelevant compounds and, more importantly, irrelevant thermosets. See *id.*

Bauer, the secondary reference, does not correct this deficiency. Bauer discloses that polycyanurate resins are suitable for manufacturing waveguide structures, lenses, prisms, corrected lens systems, optical photoconductive fibers, substrates for optical coatings, fiber coupling, as well as for the cementing of optical components. ’159 at col. 3, line 66 to col. 4, line 4. First, like Kennedy, it does not disclose Applicants’ claimed invention of having at least “(a) a first material selected from a poly(perfluorocyclobutane); in direct contact with (b) a second material selected

from a polycyanate resin (co)polymerized from at least one difunctional cyanate" of formula (I). At best, it discloses an optical element comprising plastic, wherein the plastic is a polycyanurate resin. *Id.* at col. 5, lines 34-35. Second, Bauer has a general disclosure, in this case a list of suitable uses for polycyanurate resins, which is not sufficient by itself to establish a prima facie case of obviousness. See M.P.E.P. §2144.08.

The Examiner's reliance on Bauer is nothing more than an obvious to try argument, which the M.P.E.P. has expressly rejected. M.P.E.P. § 2143.01. Applicants respectfully remind the Examiner that, in moving from the prior art to the claimed invention, one cannot base a determination of obviousness on what the skilled person might try or find obvious to try. See e.g., M.P.E.P. § 2145, Section X, Subsection B. Rather, the proper test requires determining what the prior art would have led the skilled person to do. See *In re O'Farrell*, 7 U.S.P.Q.2d 1673 (Fed. Cir. 1988). Moreover, as previously noted, the motivation to combined the references must "be found in the prior art, and not be based on applicant's disclosure." M.P.E.P. § 2143. Here, only Applicants' disclosure provide such motivation.

Finally, the Examiner has not establish a reasonable expectation of success for the proposed combination. Kennedy provides no indication on how to select a core or cladding material compatible with the PFCB to make an optical waveguide. A person of ordinary skill in the art knows that the selection requirements for making an optical waveguide are several and not trivial. For example, the low refractive index and a high curing temperature of the PFCB must be taken into account. Yet neither Kennedy nor

Bauer provide how to do so. Thus, there is no reasonable expectation of success for the proposed combination of Kennedy in view of Bauer.

Accordingly, Applicants submit that the Examiner has failed to satisfy the burden of establishing a *prima facie* case of obviousness with respect to claims 7-16 of the presently claimed invention, and respectfully requests that the § 103 rejection be withdrawn. Thus, Applicants respectfully submit that this rejection is improper and respectfully request that they be withdrawn.

**V. Conclusion**


In view of the foregoing amendments and remarks, Applicants respectfully requests reconsideration and reexamination of this application and the timely allowance of the pending claims.

Please grant any extensions of time required to enter this response and charge any additional required fees to our deposit account no. 06-0916.

Respectfully submitted,

FINNEGAN, HENDERSON, FARABOW,  
GARRETT & DUNNER, L.L.P.

Dated: July 15, 2004

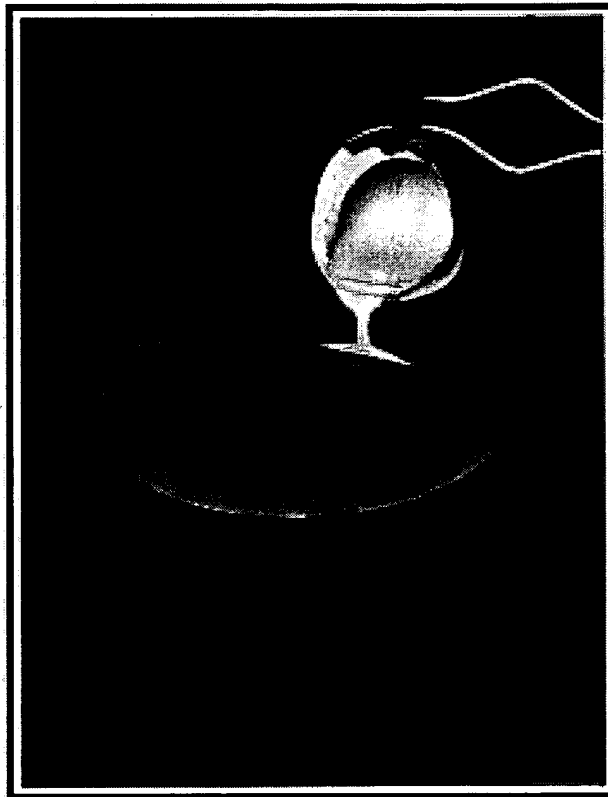
By:   
Anthony A. Hartmann  
Reg. No. 43,662

**Attachments:**

1. IUPAC Recommendations on Macromolecular (Polymer) Nomenclature.
2. Pacific Northwest National Laboratory, *Materials Science and Technology Teacher Handbook: Polymers* (U.S. Department of Energy).

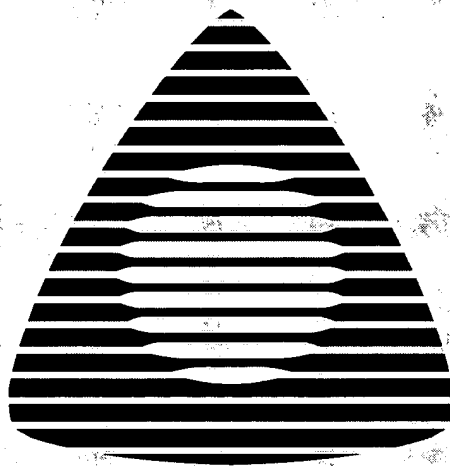


# **Materials Science and Technology Teachers Handbook**



**Pacific Northwest National Laboratory  
Richland, Washington**

# **Materials Science and Technology Teachers Handbook**



**Science Education Programs  
Pacific Northwest National Laboratory\*  
Richland, Washington**

**\*Operated by Battelle Memorial Institute  
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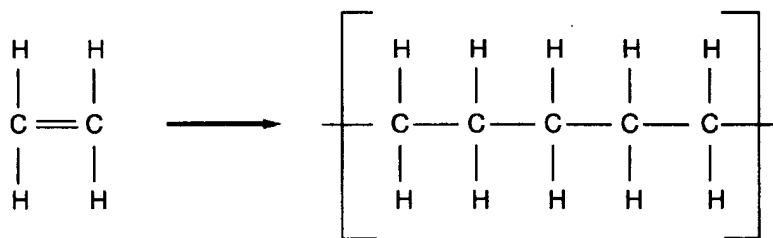
# Polymers

## Introduction

As you look around, you will find plastic materials almost everywhere. Plastics are part of a chemical family called polymers, which also includes elastomers (rubber) and adhesives. Some polymers, such as cellulose are naturally occurring, but most are chemically synthesized using chemicals derived from petroleum, which are called petrochemicals. The main petrochemical used for making polymers is natural gas.

Petroleum is a widely used product in our world, consuming billions of gallons daily for powering everything from automobiles to motorbikes and producing other forms of power (i.e., electricity through power generation). Petrochemicals use only 5% of this available petroleum, and only about half of the petrochemicals go into making polymeric materials.

Polymers (poly-mers), meaning many units, are created by joining together monomers (single units, usually a chemical compound such as ethylene gas as demonstrated in the example), using various combinations of heat, pressure, and catalysts. For instance, polyethylene is created by polymerizing ethylene gas as shown in the following chemical equation. A combination of heat, pressure, and a catalyst cause the double bond between the two carbon atoms in the ethylene gas to break and attach to other ethylene molecules. A polyethylene molecule is thus formed.



The brackets in the above equation indicate that the polyethylene molecule continues out to very long lengths relative to the size of the carbon and hydrogen atoms.

Polymers have become such an integral part of our lives that most of the time they are not recognized. Of course, we all recognize plastic bags, pens, telephones, fast food containers, and other common things as plastic, but we often fail to recognize other important polymer applications such as contact lenses; clothing fabrics (Dacron, Orlon, Nylon, Spandex, and Rayon), carpet fibers, automobile tires, foam cushions in furniture and mattresses, shoe soles, paints, pipes,

computer chips, and masks to produce electronic "chips," automobile bumpers, and innumerable other objects. Plastics influence our lifestyle more than we could ever imagine. If we ever were to use just natural fibers (cotton and wool) instead of polymeric fibers for clothing, carpets, etc., all the available land in the United States would have to be used to raise sheep or cotton to maintain our present lifestyle.

## Classification of Plastics

### Thermoplastic

Basically, two types of plastics exist, thermoplastics and thermosets. Thermoplastics can be melted and reformed or reused. Typical thermal plastics include polyethylene, polypropylene, PVC, and nylon. Thermoplastics are converted to usable products by melt processing, (injection molding, extrusion, blow molding, and thermofoaming) which are explained below.

Injection molding forces melted polymer into a cold mold under pressure. When the polymer cools, it produces a part such as a pen barrel, a comb, a Tupperware container, a garbage can, or a refrigerator liner. Extrusion forces the melted polymer through a die to form continuous shapes such as pipe, tubing, sheet, or decorative molding. Blow molding uses air pressure to blow up the melted plastic like a balloon inside of a mold. When the plastic cools, it forms a bottle or other hollow shape. Thermoforming takes heated sheets of plastic and draws them into a mold with a vacuum to form such things as butter tubs, drinking glasses, small boats, and pick-up-truck bed liners.

### Thermoset

Thermoset polymers "cure" or crosslink by a chemical process to become a stable material that cannot be melted. Typical thermosets include epoxy, polyester, phenolic, polyurethane, and silicone.

Thermoset materials are often used with reinforcements such as glass, Kevlar, and carbon fibers to make strong, lightweight parts such as fiberglass boats, airplane wing panels, Corvette car bodies, skis, gasoline storage tanks, septic tanks, chemically resistant pipe, and many other things. They are also used as adhesives that can be formulated to bond almost anything.

Some thermosets are very hard and tough (bowling balls), while others are soft and pliable (rubber tires, balloons, baby squeeze toys). Some are used for paints and some for bonding thin sheets of wood to make plywood.

## Slime

### Instructor Notes

#### **Reliability**

This lab works very well. It does take time for the polyvinyl alcohol to dissolve. Make sure the solution is clear.

#### **Estimated Time for Activity**

One class period.\*

#### **Teacher Tips**

1. Polyvinyl alcohol can be purchased as a solid or as a 4% solution from supply houses. If it is purchased as a solid, you need to get a 99% hydrated, 170,000 + molecular weight variety.
2. Adding the 4% sodium borate causes the establishment of cross links making the "slime." To make 100 mL of a 4% solution, add 8 g of  $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$ .
3. To speed the process of making slime, the polyvinyl alcohol can be dissolved ahead of time. A very quick method with very little mess is to place the solid polyvinyl alcohol and water in a capped, appropriately sized jar or bottle and place it in a microwave. **Be sure the cap is not on tight.** Heat in the microwave for about 2 min. This should make the water very warm but not hot. Tighten cap and, shake for a minute or two. If it has not all dissolved, heat for an additional minute (**loosen cap again**) and shake. This method eliminates the sticky gooey mess of stirring and heating for a pro-longed period on a hot plate. The solution dissolves very readily this way and gives a nice clear solution.
4. Adding food coloring is not necessary. It gives color only.
5. If students take the product home, they should realize it does not keep well. If left uncovered, it dries out. If left sealed, after handling, mold will begin growing on it in a few days.
6. Solutions of polyvinyl alcohol and sodium borate are stable and can be stored indefinitely.
7. References: Casassa, et al. 1986. "The Gelation of Polyvinyl Alcohol with Borax." *Journal of Chemical Education*, vol. 63, 70.1 pp. 57-60.

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\*One class period is approximately 1 hour.

**Suggested Questions**

8. Describe the polyvinyl alcohol solution before the borate (cross-link) is added.
9. Write a paragraph describing the product.
10. Is it a solid or a liquid?
11. What does "poly" mean?
12. What does "polymer" mean?
13. What does the cross-link do when it is added to the polymer? How is the viscosity of the solution affected and why?

**Safety**

1. The polyvinyl alcohol is FDA-approved for indirect food use (food packaging) and ophthalmologic (eye treatment) solutions, i.e., contact lens solutions. A 1959 study determined polyvinyl alcohol was an animal carcinogen (Flynn Scientific Chemical Catalog, 1992).

## ***Activity: Slime***

### ***Student Learning Objectives***

At the end of the activity students will be able to:

- observe and describe the properties of a prepared substance
- describe the nature of a polymer
- describe how crosslinking affects a polymer using models, drawings, discussion, and writing.

### ***Materials***

- Water, 96 mL
- Food coloring, a few drops
- Polyvinyl alcohol, 4.0 g
- Sodium borate, 4% solution (6 mL)
- Paper cup, 6 oz

### ***Equipment***

- Beaker, 250 mL
- Stirring rod
- Thermometer
- Graduated cylinder, 100 mL
- Graduated cylinder, 10 mL
- Plastic sandwich bag
- Hot plate

### ***Procedure***

1. Measure out 96 mL of water into a 100-mL graduated cylinder.
2. Carefully pour the water into a 250-mL beaker, and place it on a hot plate.
3. Heat the water to near boiling (95°C, approximately).
4. Add a few drops of food coloring to the warm water, if desired.
5. Accurately weigh out 4.0 g of polyvinyl alcohol into a 6-oz. paper cup.
6. Remove the water from the hot plate. Slowly, while stirring, add the polyvinyl alcohol to the warm water.

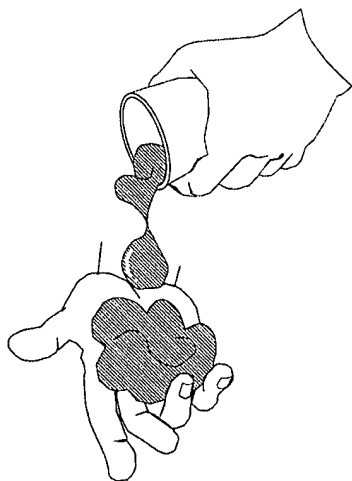


Figure 7.1. Slime

7. Place the beaker back on the hot plate until the temperature reaches about 90°C. Keep stirring until the polyvinyl alcohol is completely dissolved. Be patient.
8. Add 6 mL of 4% sodium borate, stirring constantly as you add the solution.
9. Pour the product into your plastic sandwich bag to cool before studying its properties.
10. Clean your equipment. (Hint: Roll product around in beaker to clean out most of the product, then wash.)
11. As students study the material they enjoy handling it. Have students try pouring it into their hands (Figure 7.1).

### ***Extension Activity***

1. Try adding more polyvinyl alcohol or a stronger or weaker concentration of sodium borate to the slime. Observe how these chemical changes affect the properties of the materials. Be sure and record this information in your journal.
2. Use a funnel or cheap paint "viscosity cup" to note the effect of changing variables on the viscosity of a product.

**Note:** *Viscosity is an indirect indication of the amount of cross-linking that has taken place.*



# IUPAC Recommendations on Macromolecular (Polymer) Nomenclature

## Guide for Authors of Papers and Reports in Polymer Science and Technology

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This Guide is easy to follow and a less formal approach to macromolecular nomenclature than the official IUPAC recommendations, all of which had been previously published in *Pure and Applied Chemistry*.

It has been the goal of the IUPAC Commission on Macromolecular Nomenclature to improve communication between polymer scientists by recommending unambiguous, standardized, and universally understood names and structure representations of polymers.

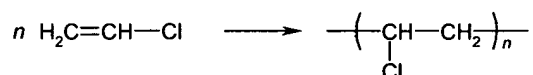
### A. International Union of Pure and Applied Chemistry (IUPAC) Recommendations

A substance referred to as "a polymer" is different from a low-molecular-weight or "non-polymeric" substance in that usually it has no uniform structure; rather, it consists of a mixture of individual macromolecules. Each macromolecule has a different structural arrangement and length from the others in the mixture. These differences arise from such features as irregularity in monomeric unit sequences within chains, branching irregularities, monomeric unit orientation, and end-group structure.

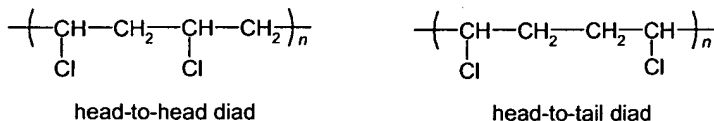
For all types of polymers – single-strand organic, double-strand organic, single-strand inorganic, and coordination – the nomenclature guidelines usually apply to structural representations that are idealized or theoretical; considerations of chain branching, imperfections, or irregularities are excluded.

Because of these problems, attempts to define polymeric substances rigorously are impractical; graphical representation and nomenclature of polymers therefore require a different approach. Naming a polymer of partly known or unknown structure by the "structure-based nomenclature system" may be difficult or impossible unless assumptions are made; naming it by the "source-based nomenclature system" may be possible, however. (Source-based and structure-based nomenclature systems are described below.)

A reaction involving polymerization of a monomer such as vinyl chloride is generally depicted<sup>1</sup> as

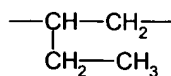
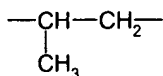


The graphical representation of the polymer is ideal rather than true; it contains no information that the polymer contains macromolecules (individual chains) of different chain lengths, and it assumes that all the repeating units are connected in an identical fashion, namely "head-to-tail". In a real polymer, each macromolecule will contain some "head-to-head" diads and some "tail-to-tail" diads.



The precise sequence in each macromolecule of head-to-head, head-to-tail, and tail-to-tail repeating units is usually unknown.

This problem applies also to copolymers; each asymmetric comonomer that can give rise to asymmetric repeating units in a chain adds to the complexity. Each repeating unit can be oriented more than one way in a chain, and also the order of repeating units from comonomers can vary within a chain. For example, the copolymer from the two comonomers 1-propene and 1-butene contains two constitutional or monomeric units:



These can be combined to give several types of copolymers such as alternating, block, graft, periodic, random, statistical, or unspecified.

For these situations, source-based nomenclature is used, which circumvents these problems. A discussion of source-based and structure-based nomenclature systems follows.

## A1. IUPAC Recommendations for Source-Based Nomenclature

### A1.1. Nomenclature for Homopolymers

A homopolymer, as the name indicates, is a polymer obtained from only one type of monomer. This may be either an actual monomer, e.g. a reactant, or a hypothetical monomer; an example of the latter is a homopolymer formed by modifying another homopolymer.

Homopolymers are named by writing the prefix “poly”, followed by the name of the actual or hypothetical monomer. Names of monomers having substituents or comprising at least two words are parenthesized. Some examples are given in Table 1.

**Table 1. Examples of Homopolymer Names**

Polymer Name	Polymer Name	Polymer Name	Polymer Name
polyacrylonitrile	poly(1,1-difluoroethylene)	poly(methacrylic acid)	poly(vinyl alcohol)
poly( <i>p</i> -bromostyrene)	poly(ethyl acrylate)	poly(propyl vinyl ether)	poly(vinyl fluoride)
polybut-1-ene	polyethylene	poly(vinyl acetate)	poly(vinylidene fluoride)

When multiple sets of parentheses or brackets are needed, IUPAC recommends the use of curved brackets (parentheses) for the innermost application, then square brackets, then curly brackets. These are applied in a “cyclical” pattern, i.e., (...), [...], {[...]}, {[{...}]}, {[{[...]}]}, etc. In contrast, Chemical Abstracts Service (CAS) uses curved brackets (parentheses) for the innermost application and square brackets for all others, i.e. (...), [...], [[...]], etc. This CAS bracketing style is sometimes used with IUPAC-style names, although it has not been officially sanctioned by IUPAC.

Except for polyethylene, all the homopolymers in Table 1 form asymmetrical constitutional units, and the orientation of each constitutional unit within a chain is generally unknown. Furthermore, different samples of any given homopolymer represented by the same constitutional unit can exhibit different chemical and physical characteristics, e.g. average molecular weight or molecular weight distribution.

### A1.2. Nomenclature for Copolymers

Any polymer derived from more than one type of monomer is usually referred to colloquially as a copolymer.<sup>2</sup> As in the case of homopolymers, each comonomer may be an actual monomer, e.g. a reactant, or a hypothetical monomer.

Copolymers are named by writing the prefix “poly”, followed by the names of the actual or hypothetical monomers; an infix, called a connective, is placed between them that indicates the type of sequential arrangement of the constitutional units within the chains.

Table 2 lists the seven types of connectives used to indicate the sequence arrangement of constitutional units; examples of copolymer names are given in Table 3.

**Table 2. IUPAC Source-Based Copolymer Classification**

Polymer Type	Connective	Example
Unspecified or unknown	-co-	poly(A-co-B)
Random (obeys Bernoullian distribution)	-ran-	poly(A-ran-B)
Statistical (obeys known statistical laws)	-stat-	poly(A-stat-B)
Alternating (for two monomeric units)	-alt-	poly(A-alt-B)

Periodic (ordered sequence for >2 monomeric units)	<i>-per-</i>	poly(A- <i>per</i> -B- <i>per</i> -C)
Block (linear block arrangement)	<i>-block-</i>	polyA- <i>block</i> -polyB
Graft (side chains connected to main chains)	<i>-graft-</i>	polyA- <i>graft</i> -polyB

**Table 3. Examples of Source-Based Copolymer Nomenclature**

Polymer name	Polymer name
Poly(propene- <i>co</i> -methacrylonitrile)	Polyacrylonitrile- <i>block</i> -polybutadiene- <i>block</i> -polystyrene
Poly[(acrylic acid)- <i>ran</i> -(ethyl acrylate)]	Poly[(ethylene oxide)- <i>per</i> -(ethylene oxide)- <i>per</i> -tetrahydrofuran]
Poly(butene- <i>stat</i> -ethylene- <i>stat</i> -styrene)	Polyisoprene- <i>graft</i> -poly(methacrylic acid)
Poly[(sebacic acid)- <i>alt</i> -butanediol]	

Table 3 contains examples of common or semi-systematic names of comonomers. The systematic names of comonomers may also be used; thus, the polyacrylonitrile-*block*-polybutadiene-*block*-polystyrene polymer in Table 3 may also be named poly(prop-2-enitrile)-*block*-polybuta-1,3-diene-*block*-poly(ethenylbenzene). IUPAC does not require alphabetized names of comonomers within a polymer name; many names are thus possible for some copolymers.

IUPAC also recommends an alternative scheme for naming copolymers that comprises use of:

1. "copoly" as a prefix, followed by the names of the comonomers
2. an oblique stroke (a solidus) to separate comonomer names
3. addition before "copoly" of any applicable connectives listed in Table 2 except *-co-*.

Table 4 gives the same examples shown in Table 3 but with the alternative format. Comonomer names need not be parenthesized.

**Table 4. Examples of Source-Based Copolymer Nomenclature (Alternative Format)**

Polymer name
copoly(propene/methacrylonitrile)
<i>ran</i> -copoly(acrylic acid/ethyl acrylate)
<i>stat</i> -copoly(butene/ethylene/styrene)
<i>alt</i> -copoly(sebacic acid/butanediol)
<i>block</i> -copoly(acrylonitrile/butadiene/styrene)
<i>per</i> -copoly(ethylene oxide/ethylene oxide/tetrahydrofuran)
<i>graft</i> -copoly(isoprene/methacrylic acid)

### A1.3. Nomenclature for Non-Linear Macromolecules and Macromolecular Assemblies

A 1997 IUPAC document<sup>3</sup> covers source-based nomenclature for non-linear macromolecules, such as branched, comb, cyclic, graft, network, and star polymers, and macromolecular assemblies, such as interpenetrating polymer networks, polymer blends, and polymer-polymer complexes. The types of polymers in these classes, together with their connectives, are given in Table 5; the terms shown may be used as connectives, prefixes, or both to designate the features present.

**Table 5. Connectives for Non-Linear Macromolecules and Macromolecular Assemblies**

Type	Connective	Type	Connective
Branched (type unspecified)	<i>branch</i>	Network	<i>net</i>
Branched with branch point of functionality f	<i>f-branch</i>	Polymer blend	<i>blend</i>
Comb	<i>comb</i>	Polymer-polymer complex	<i>compl</i>
Cross-link	$\nu$ (Greek nu)	Semi-interpenetrating polymer network	<i>sipn</i>
Cyclic	<i>cyclo</i>	Short-chain branched	<i>sh-branch</i>
Interpenetrating polymer network	<i>ipn</i>	Star	<i>star</i>
Long-chain branched	<i>l-branch</i>	Star with f arms	<i>f-star</i>

Non-linear polymers are named by using the italicized connective as a *prefix* to the source-based name of the polymer component or components to which the prefix applies; some examples are listed in Table 6.

**Table 6. Examples of Connectives Used as Prefixes for Non-Linear Macromolecules**

Polymer Name	Polymer Structural Features
Poly(acrylic acid)- <i>comb</i> -polyacrylonitrile	Comb polymer with a poly(acrylic acid) backbone and polyacrylonitrile arms
<i>Comb</i> -poly[ethylene- <i>stat</i> -(vinyl chloride)]	Comb polymer with unspecified backbone composition and statistical ethylene/vinyl chloride copolymer arms
Polybutadiene- <i>comb</i> -(polyethylene; polypropene)	Comb polymer with butadiene backbone and arms of polyethene and polypropene
<i>Star</i> -(polyA; polyB; polyC; polyD)	Star polymer with every arm containing comonomers A, B, C, and D
<i>Star</i> -(polyA- <i>block</i> -polyB- <i>block</i> -polyC)	Star polymer with every arm comprising a tri-block segment containing comonomers A, B, and C
<i>Star</i> -poly(ethylene oxide)	A star polymer prepared from ethylene oxide
6- <i>star</i> -poly(ethylene oxide)	A 6-arm star polymer prepared from ethylene oxide
<i>Star</i> -(polyacrylonitrile; polyethylene) ( $M_r$ 20000: 50000)	A star polymer containing polyacrylonitrile arms of MW 20000 and polyethylene arms of MW 50000

Macromolecular assemblies held together by forces other than covalent bonds are named by inserting the appropriate italicized connective between names of individual components; Table 7 gives examples.

**Table 7. Examples of Connectives Used for Polymer Blends and Nets**

Polymer Name
polyethylene- <i>blend</i> -polybutene
poly(methacrylic acid)- <i>blend</i> -poly(methyl methacrylate)
<i>net</i> -poly(4-methylstyrene- <i>v</i> -divinylbenzene)
<i>net</i> -poly[styrene- <i>alt</i> -(maleic anhydride)]- <i>v</i> -(polyethylene glycol; polypropylene glycol)
<i>net</i> -poly(ethyl acrylate)- <i>sipn</i> -polyethylene
[ <i>net</i> -poly(butadiene- <i>stat</i> -4-ethylstyrene)]- <i>ipn</i> -[ <i>net</i> -poly(4-ethylstyrene- <i>v</i> -divinylbenzene)]

## A2. IUPAC Recommendations for Structure-Based Nomenclature



### A2.1. Nomenclature for Regular Single-Strand Organic Polymers

Regular, single-strand organic polymers consisting of one type of constitutional repeating unit (CRU) in a single sequential unit are named:

poly(constitutional repeating unit)

The complete repeating group is named as a bivalent organic group according to IUPAC recommendations for naming organic compounds.<sup>4</sup> Each CRU comprises one or more subunits, each of which may carry substituents; some examples of subunits are given in Table 8.

**Table 8. Examples of Bivalent Moieties Typically Used as Constitutional Subunits<sup>a</sup>**

Name	Structure	Name	Structure
1-bromoethylene	$\text{—}\underset{\text{Br}}{\text{CH}}\text{—CH}_2\text{—}$	1-methylethane-1,1-diyl <sup>d</sup>	$\text{H}_3\text{C—}\underset{\text{—C—}}{\text{C}}\text{—CH}_3$
butane-1,4-diyl	$\text{—CH}_2\text{—CH}_2\text{—CH}_2\text{—CH}_2\text{—}$	1-oxoethane-1,2-diyl	$\text{—}\overset{\text{O}}{\underset{\text{  }}{\text{C}}}\text{—CH}_2\text{—}$
1-(chloromethyl)ethylene	$\text{—}\underset{\text{CH}_2\text{Cl}}{\text{CH}}\text{—CH}_2\text{—}$	oxy	$\text{—O—}$
cyclohexane-1,2-diyl		1,2-phenylene <sup>e</sup>	

dimethylsilanediyl	$\begin{array}{c} \text{H}_3\text{C} \quad \text{CH}_3 \\ \diagdown \quad / \\ \text{—Si—} \end{array}$	piperazine-1,4-diyl	
ethane-1,1-diyl <sup>b</sup>	$\begin{array}{c} \text{—CH—} \\   \\ \text{CH}_3 \end{array}$	propylimino	$\begin{array}{c} \text{—N—} \\   \\ \text{CH}_2\text{—CH}_2\text{—CH}_3 \end{array}$
ethene-1,2-diyl <sup>c</sup>	$\text{—CH=CH—}$	pyridine-3,5-diyl	
ethylene	$\text{—CH}_2\text{—CH}_2\text{—}$	silanediyl	$\text{—SiH}_2\text{—}$
hydrazo	$\text{—NH—NH—}$	succinyl <sup>f</sup>	$\begin{array}{c} \text{O} \quad \text{O} \\    \quad    \\ \text{—C—(CH}_2\text{)}_2\text{—C—} \end{array}$
imino	$\text{—NH—}$	sulfanediyl <sup>g</sup>	$\text{—S—}$
methylene	$\text{—CH}_2\text{—}$	sulfonyl	$\text{—SO}_2\text{—}$

<sup>a</sup>Even when substitution is present, the largest subunit possible is selected for naming. Examples: ethylene is not called “methylenemethylene”; terephthaloyl is not called “carbonyl-*p*-phenylenecarbonyl”;  $\text{—CH}_2\text{—CO—CH}_2\text{—CH}_2\text{—}$  is called 2-oxobutane-1,4-diyl, not “methylenecarbonylethylene”.

<sup>b</sup>TUPAC no longer recommends ethylidene as a name for this subunit when it is connected to two different atoms.

<sup>c</sup>TUPAC still permits vinylene as a name for this subunit, but ethene-1,2-diyl is preferred.

<sup>d</sup>TUPAC no longer recommends isopropylidene as a name for this subunit.

<sup>e</sup>Both *o*-phenylene and 1,2-phenylene are permitted; IUPAC similarly permits both *m*-phenylene and 1,3-phenylene, and both *p*-phenylene and 1,4-phenylene.

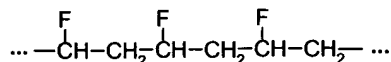
<sup>f</sup>Other similar subunit names permitted include adipoyl, glutaryl, isophthaloyl, malonyl, oxalyl, phthaloyl, and terephthaloyl.

<sup>g</sup>TUPAC still permits thio as a name for this subunit, but sulfanediyl is preferred.

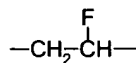
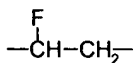
Before a CRU can be **named**, it must be **identified** (i.e. the subunits of which it is comprised must be determined); and it must be **oriented** i.e., written in a manner that follows the guidelines developed by both IUPAC<sup>4</sup> and CAS.<sup>5</sup> IUPAC uses “poly(constitutional repeating unit)” or poly(CRU), whereas CAS names a polymer as “poly(structural repeating unit)” or poly(SRU); the two terms are virtually identical. The nomenclature principles devised by CAS and IUPAC are nearly identical, but names of CRUs (or SRUs) derived by the two organizations are sometimes different because CAS and IUPAC use different names for some subunits. The isopropylidene subunit is a commonly encountered example: CAS names it 1-methylethylidene whereas IUPAC names it 1-methylethane-1,1-diyl.

For most polymer structures, the CRU can be written in more than one way.

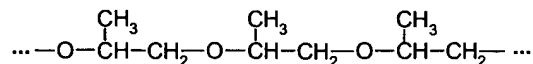
**Example 1:** in a simple polymer, such as



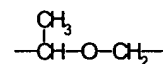
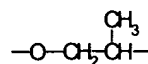
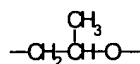
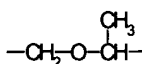
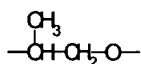
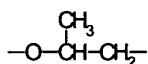
there are two CRUs:



**Example 2:** in a more complex polymer, such as



there are six CRUs:



In Example 1, one of the two CRUs must be selected as the preferred one; similarly, in Example 2, one of the six CRUs must be selected as the preferred one. In each example, the preferred CRU must then be oriented before it can be named correctly.

The complete process of identifying, orienting, and naming a CRU involves three steps, which must be carried out in the order listed:

**Step A: *Identifying*** the CRU: this is best achieved by drawing an extended segment of the chain that contains at least two constitutional repeating units.

**Step B: *Orienting*** the CRU: this is the most challenging step. Guidelines are given below for most types of CRU, but comprehensive coverage of all the guidelines is outside the scope of this article.

**Step C: *Naming*** the complete CRU: the CRU oriented in Step B is named as a bivalent organic group according to the usual nomenclature guidelines for organic chemistry.

The guidelines presented below were designed to enable determination of: (1) *seniority* among subunits, i.e., which subunit is written leftmost in the complete CRU; and (2) the *direction* along the chain in which to continue to the end of the CRU.

**(1) *Seniority***

Among the bivalent subunits that comprise a single-strand CRU, the order of seniority is:

**Subunit type (a):** moieties comprising heterocycles

Examples: piperidine-3,5-diyl  
thiophene-2,5-diyl

**Subunit type (b):** hetero-atomic acyclic moieties

Examples: imino  
oxy  
sulfanediyl  
sulfonyl

**Subunit type (c):** moieties comprising carbocycles

Examples: 1,3-phenylene  
cyclohexane-1,3-diyl

**Subunit type (d):** moieties comprising carbon chains

Examples: 1-chloroethylene  
propane-1,3-diyl

Seniority within subunit types (a) - (d) is determined by further guidelines:

**Subunit type (a):** heterocycles. A nitrogen-containing ring system is senior to a ring system containing a hetero atom other than nitrogen.<sup>4,6</sup> Further descending order of seniority is determined by:

- (i) the highest number of rings in the ring system
- (ii) the largest individual ring in the ring system
- (iii) the largest number of hetero atoms
- (iv) the greatest variety of hetero atoms

**Subunit type (b):** hetero-atomic acyclic moieties. The senior bivalent subunit is the one nearest the top, right-hand corner of the periodic table; the order is: O, S, Se, Te, N, P, As, Sb, Bi, Si, Ge, Sn, Pb, B, Hg.

**Subunit type (c):** carbocyclic moieties. Seniority<sup>4</sup> is determined by:

- (i) the highest number of rings in the ring system
- (ii) the largest individual ring in the ring system
- (iii) degree of ring saturation; an unsaturated ring is senior to a saturated ring of the same size

**Example 3:** A 3-ring system is senior to a 2-ring system.

**Example 4:** A 2-ring system with two 6-membered rings is senior to a 2-ring system with one 6-membered and one 5-membered ring.

**Example 5:** A fused 2-ring system (two atoms common to both rings) is senior to a spiro 2-ring system (one atom common to both rings).<sup>7</sup>

**Subunit type (d):** carbon-containing acyclic groups. Descending order of seniority is determined by:

- (i) chain length (longer is senior to shorter)
- (ii) number of substituents (higher number is senior to lower number)
- (iii) ascending order of locants
- (iv) alphabetical order of names of substituent groups

The seniority guidelines given above are applied only to the subunits of the main chain or backbone. Substituents in main-chain subunits, whether the subunits are of type (a), (b), (c), or (d), do not control CRU selection unless otherwise identical chain subunits need to be differentiated by either the number of substituents or their alphabetical order.

## (2) Direction

The preferred CRU is the one that begins with the subunit of highest seniority and continues along the chain in the direction of either (1) another occurrence of the same subunit or (2) the subunit next in seniority. If, in (1), there is more than one further occurrence of the same subunit, the preferred path is the shorter one between the senior subunit and one of its further occurrences.

**Example 6:** consider the CRU ...C-C-O-C-C-S-C-C-O-C-C-O-C-C-S-C-C-O-C...

$$\begin{array}{cccccccc} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 \\ 8 & 7 & 6 & 5 & 4 & 3 & 2 & 1 \end{array}$$

**Identifying** the CRU: this CRU has a regularly repeating eight-atom sequence. Thus, starting from one sulfur atom and proceeding along the chain in either direction as far as (but not including) the next sulfur atom results in the conclusion that the CRU contains eight atoms. This sequence also contains two oxygen atoms.

**Orienting** the CRU: there are no heterocycles [subunit type (a)] present; therefore one of the hetero atoms [subunit type (b)] must be the senior subunit. O is senior to S (see above), and therefore one of the two oxygen atoms must be selected as senior subunit. Numbering the two oxygen atoms arbitrarily O<sup>1</sup> and O<sup>2</sup> gives:

...C-C-O<sup>1</sup>-C-C-S-C-C-O<sup>2</sup>-C-O<sup>1</sup>-C-C-S-C-C-O<sup>2</sup>-C...

Beginning with either occurrence of O<sup>1</sup> and proceeding along the chain in the *direction* of the second subunit of equal seniority, O<sup>2</sup>, as far as (but not including) a second occurrence of O<sup>1</sup>, gives two possibilities, each eight atoms long (for this determination, reading in either direction is permissible):

- (1) -O<sup>1</sup>-C-C-S-C-C-O<sup>2</sup>-C-
- (2) -C-C-S-C-C-O<sup>2</sup>-C-O<sup>1</sup>-

According to the guidelines, the preferred path from O<sup>1</sup> to O<sup>2</sup> is the shorter one; of the two possibilities shown immediately above, therefore, sequence (2), when laterally reversed from -C-C-S-C-C-O<sup>2</sup>-C-O<sup>1</sup>- to -O<sup>1</sup>-C-O<sup>2</sup>-C-C-S-C-C-, becomes the preferred CRU.

The **defined** and **oriented** CRU is thus -O-C-O-C-C-S-C-C-. It may now be **named**:

1. Select the names of its subunits (e.g. from Table 8) in the order in which they occur as the sequence is read from left to right;
2. Write them in the order in which they were selected;
3. Precede the subunit name assembly with poly; use parentheses, brackets, or both, as necessary.

The preferred name for this CRU, written in the style "poly(constitutional repeating unit)", is thus poly(oxymethyleneoxyethylenesulfanediyethylene); poly(oxymethyleneoxyethylenethioethylene) is an acceptable alternative.

Application of these guidelines to example 2, ...-O-CH(CH<sub>3</sub>)-CH<sub>2</sub>..., gives the following results:

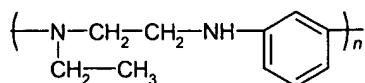
1. O is the senior subunit
2. For the substituted ethylene subunit, the preferred position for the methyl group is on the leftmost carbon, i.e., it is assigned the lowest possible locant when reading from left to right

The name of the polymer is thus poly[oxy(1-methylethylene)].<sup>8</sup>

Two more examples are shown to illustrate application of the guidelines.



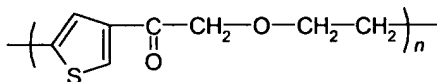
**Example 6:** poly[(ethylimino)ethyleneimino-1,3-phenylene] has the following structure:



The steps that led to this orientation and name were:

1. One of the two nitrogen atoms is the senior subunit.
2. The substituted N is senior to the unsubstituted one [see **subunit type (d)(ii)** above].
3. The shorter path from the senior N to the unsubstituted N is via the ethylene subunit (two atoms between the two N atoms), not via the ring (three atoms between the two N atoms).

**Example 7:** poly[thiophene-2,4-diyl(1-oxoethylene)oxyethylene] has the following structure:



The steps that led to this orientation and name were:

1. The heterocycle is the senior subunit.
2. The path length from the senior subunit to -O-, the next senior subunit, is the same in both directions along the CRU. Guideline **subunit type (d)(ii)** is used to make a decision between the two paths of equal length; the substituted subunit (1-oxoethylene) is senior to the unsubstituted subunit (ethylene).

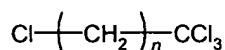
The procedure for naming end-groups on CRUs is as follows:

1. Identify, orient, and name the CRU per the guidelines above
2. Name the end-groups as substituents; use parentheses, brackets, or both, as necessary
3. Precede the name of the left-hand end-group by the Greek letter  $\alpha$
4. Precede the name of the right-hand end-group by the Greek letter  $\omega$
5. Assemble the complete name in the format:

$\alpha$ -(left-hand end-group)- $\omega$ -(right-hand end-group)poly(CRU)

For symmetrical CRUs, e.g. poly(methylene), end-group names are alphabetized; the end-group that alphabetizes first is designated as the  $\alpha$  end-group (see Example 8).

**Example 8:**  $\alpha$ -chloro- $\omega$ -(trichloromethyl)poly(methylene)



For asymmetrical CRUs in which the two end-group names are different from one another, the  $\alpha$ -end-group is cited first, regardless of alphabetic order (see Example 9).

**Example 9:**  $\alpha$ -(trichloromethyl)- $\omega$ -chloropoly(1,1-difluoroethylene)

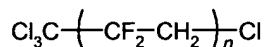
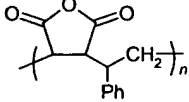
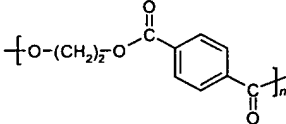
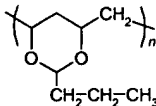


Table 9 compares and contrasts structure-based and source-based names for some common polymers.

**Table 9. Structure-Based, Source-Based, and Trivial Names for Some Common Polymers**

Structure	Structure-Based Names	Source-Based and Trivial Names
	Poly(1-acetoxyethylene)	Poly(vinyl acetate)
	Poly(but-1-ene-1,4-diyl)	Polybutadiene <sup>a</sup>

$\left( \text{CH}(\text{Cl})\text{CH}_2 \right)_n$	Poly(1-chloroethylene)	Poly(vinyl chloride)
$\left( \text{CH}(\text{CN})\text{CH}_2 \right)_n$	Poly(1-cyanoethylene)	Polyacrylonitrile
$\left( \text{CF}_2\text{CH}_2 \right)_n$	Poly(1,1-difluoroethylene)	Poly(vinylidene difluoride)
$\left( \text{CF}_2 \right)_n$	Poly(difluoromethylene) <sup>b</sup>	Poly(tetrafluoroethylene)
$\left( \text{C}(\text{CH}_3)_2\text{CH}_2 \right)_n$	Poly(1,1-dimethylethylene)	Polyisobutylene
	Poly[(2,5-dioxotetrahydrofuran-3,4-diyl)(1-phenylethylene)]	Poly(maleic anhydride- <i>alt</i> -styrene)
$\left( \text{CH}(\text{OH})\text{CH}_2 \right)_n$	Poly(1-hydroxyethylene)	Poly(vinyl alcohol)
$\left[ \text{NH}-\text{C}(=\text{O})-(\text{CH}_2)_4-\text{C}(=\text{O})-\text{NH}-(\text{CH}_2)_6 \right]_n$	Poly(iminoadipoyliminohexane-1,6-diyl)	Poly(adipic acid- <i>alt</i> -hexamethylenediamine); nylon 66; poly(hexamethylene adipamide)
$\left[ \text{NH}-\text{C}(=\text{O})-(\text{CH}_2)_5 \right]_n$	Poly[imino(1-oxohexane-1,6-diyl)]	Poly(ε-caprolactam); nylon 6
$\left( \text{C}(\text{CH}_3)(\text{CO}_2\text{CH}_3)\text{CH}_2 \right)_n$	Poly[1-(methoxycarbonyl)-1-methylethylene]	Poly(methyl methacrylate)
$\left( \text{CH}_2 \right)_n$	Poly(methylene) <sup>b</sup>	Polyethene; polyethylene
$\left( \text{O}-\text{CH}_2\text{CH}_2 \right)_n$	Poly(oxyethylene)	Poly(oxirane); poly(ethylene oxide)
	Poly(oxyethyleneoxyterephthaloyl)	Poly(ethylene terephthalate); PET
$\left( \text{O}-\text{C}_6\text{H}_4 \right)_n$	Poly(oxy-1,4-phenylene)	Poly(phenylene oxide)
$\left( \text{CH}(\text{CH}_3)\text{CH}_2 \right)_n$	Poly(1-methylethylene)	Polypropylene; polypropene
$\left( \text{CH}(\text{Ph})\text{CH}_2 \right)_n$	Poly(1-phenylethylene)	Poly(ethenylbenzene); polystyrene
	Poly[(2-propyl-1,3-dioxane-4,6-diyl)methylene]	Poly(vinyl butyral)

<sup>a</sup>This assumes polymerization of poly(butadiene) in the so-called “1,4” mode, for which the CRU is usually written  $-\text{[CH}_2\text{-CH=CH-CH}_2\text{]}_n-$ . According to CAS and IUPAC guidelines, this is incorrect; the correct

<sup>b</sup>Structure-based representations  $-(CH_2)_n-$  and  $-(CF_2)_n-$  are preferred for poly(methylene) and poly(difluoromethylene), respectively; however, because of past usage and an attempt to retain some similarity to the CRU formulas of homopolymers derived from other ethene derivatives, the CRU representations  $-(CH_2-CH_2)_n-$  and  $-(CF_2-CF_2)_n-$  are also acceptable.

The naming of each constitutional unit of an irregular, single-strand organic polymer follows the guidelines in section A2.1 above. The complete polymer name is constructed by combining names of individual constitutional units, separating them with as many solidi (oblique strokes) as necessary, parenthesizing or bracketing the complete expression, and adding the prefix “poly”.<sup>9</sup> The solidus is used to indicate that information is unavailable on the individual CRU sequence in the polymer. In graphical representations of these polymers, the hyphens or dashes at each end of each CRU depiction are shown *completely within* the enclosing parentheses; this indicates that they are not necessarily the terminal bonds of the macromolecule. The examples in table 10 illustrate application of these guidelines.

Structure	Name
$\left( \text{--CH=CH--CH}_2\text{--CH}_2\text{--} / \text{--}\underset{\text{CH=CH}_2}{\text{CH--CH}_2}\text{--} \right)_n$	Poly(but-1-ene-1,4-diyl/1-vinylethylene) Note: depiction of the product from polymerization of buta-1,3-diene in the so-called "1,2-" and "1,4-" modes
$\left( \text{--}\underset{\text{Cl}}{\text{CH--CH}_2}\text{--} / \text{--}\underset{\text{Ph}}{\text{CH--CH}_2}\text{--} \right)_n$	Poly(1-chloroethylene/1-phenylethylene) Note: representation of a copolymer of vinyl chloride and styrene
$\left( \text{--CH}_2\text{--} / \text{--}\underset{\text{Cl}}{\text{CH--}} / \text{--}\underset{\text{Cl}}{\text{C--}} \right)_n$	Poly(dichloromethylene/chloromethylene/methylene) Note: representation of the idealized product from chlorination of poly(ethylene), and also from chlorination of poly(vinyl chloride)
$\left( \text{O} \begin{array}{c} \parallel \\ \text{C} \\ \mid \\ \text{CH--CH}_2 \end{array} \text{--CH}_3 / \text{--}\underset{\text{OH}}{\text{CH--CH}_2}\text{--} \right)_n$	Poly(1-acetoxyethylene/1-hydroxyethylene) Note: representation of partially hydrolyzed head-to-tail poly(1-acetoxyethylene)
$\left( \text{--}\underset{\text{OH}}{\text{CH--CH}_2}\text{--} / \text{--}\underset{\text{O} \begin{array}{c} \parallel \\ \text{C} \\ \mid \\ \text{CH}_2\text{CH}_2\text{CH}_3 \end{array}}{\text{CH--CH}_2}\text{--} / \text{--} \begin{array}{c} \text{CH}_2 \\ \diagup \quad \diagdown \\ \text{O} \quad \text{O} \\ \diagdown \quad \diagup \\ \text{CH}_2\text{CH}_2\text{CH}_3 \end{array} \right)_n$	Poly[(1-acetoxyethylene)/(1-hydroxyethylene)/[(2-propyl-1,3-dioxane-4,6-diyl)methylene]] Note: representation of poly(vinyl alcohol) partially converted to poly[(vinyl acetate)-co-(vinyl butyral)]

Every macromolecule in a double-strand polymer contains a continuous sequence of rings; there are no single, acyclic bonds. Spiro polymers have one atom in common in adjacent rings. Ladder polymers have two or more atoms in common in adjacent rings. As for linear single-strand polymers, a double-strand polymer CRU must be identified and oriented before the polymer can be named.<sup>6</sup> The CRU is a multivalent group (usually tetravalent) in which attachment to all (usually four) atoms is cited. The CRU is named according to the IUPAC guidelines for organic nomenclature.<sup>4</sup> The polymer is named in the style

**Guideline 3: Maintain intact the most preferred ring system.**<sup>4</sup>

Further decisions are based upon:

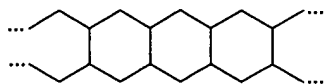
**Guideline 4:** Ring system seniority<sup>4,5</sup>

**Guideline 5:** Orientation of the CRU to place the lowest free-valence locant at the lower-left position of the structural diagram

**Guideline 6:** Placement of any acyclic subunits on the right side of the structural diagram, within the CRU

Three examples are shown to illustrate application of the guidelines.

**Example 10:** For the ladder polymer



comprising adjacent, six-membered, saturated carbon rings, the preferred CRU is an acyclic subunit of four carbon atoms with four free valencies, one at each atom. The lower-left atom is assigned the lowest locant.

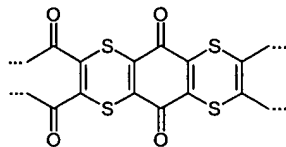


Within the CRU name, the free-valence locants are written immediately before the end of the tetravalent unit to which they apply. The locants are cited clockwise from the lower-right position; thus, they are always cited, complete with punctuation (commas and colon), in the following order and manner:

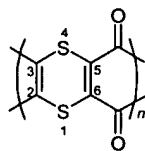
lower-left, upper-left:upper-right, lower-right

The name of this ladder polymer is poly(butane-1,4:3,2-tetrayl).

**Example 11:** For the ladder polymer

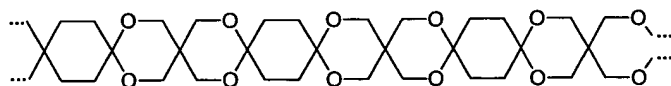


which contains one type of heterocyclic ring that alternates with one type of carbocyclic ring, the heterocyclic ring is senior to the carbocyclic ring (see **Guideline 2** above); therefore the carbocyclic ring is broken, the heterocyclic ring is placed leftmost, and the two acyclic chains resulting from fracture of the carbocyclic ring are placed to the right of the cyclic subunit (see **Guideline 6** above).

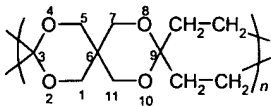


The name of this ladder polymer is poly(1,4-dithiin-2,3:5,6-tetrayl-5,6-dicarbonyl).

**Example 12:** The spiro polymer



contains three-rings – two 1,3-dioxane rings (facing in opposite directions) and a cyclohexane ring. The preferred CRU retains the two 1,3-dioxane rings, and the carbocyclic ring is broken (see **Guideline 2** above). The acyclic fragments are placed to the right of the cyclic subunits (see **Guideline 6** above).



The name of this spiro polymer is poly(2,4,8,10-tetraoxaspiro[5.5]undecane-3,3:9,9-tetrayl-9,9-diethylene).

#### A2.4. Nomenclature for Regular Single-Strand Inorganic and Coordination Polymers

IUPAC names of inorganic and coordination polymers<sup>10</sup> are based on the fundamental principles of nomenclature developed for organic polymers. The CRU must thus be *defined* and *oriented* before it can be *named*. However, owing to basic differences between inorganic and organic nomenclature, subunits of inorganic CRUs are named as inorganic or coordination groups, which include covalent or coordinate bonding, respectively. The polymer is named by attaching to the name of the CRU a suitable prefix, such as “poly” or “catena”.

CRU orientation depends upon *seniorities* of, and preferred *direction* for citation of, each constituent subunit. The principle of coordination nomenclature places emphasis on a coordination centre. The constituent subunit of highest seniority must therefore contain at least one central atom; bridging groups between central backbone atoms have lower seniority. When there are two or more central atoms in the CRU of a linear inorganic or coordination polymer, the senior subunit is the one containing the central atom occurring *latest* in the following atom sequence.<sup>10</sup>

F, Cl, Br, I, At, O, S, Se, Te, Po, N, P, As, Sb, Bi, C, Si, Ge, Sn, Pb, B, Al, Ga, In, Tl, Zn, Cd, Hg, Cu, Ag, Au, Ni, Pd, Pt, Co, Rh, Ir, Fe, Ru, Os, Mn, Tc, Re, Cr, Mo, W, V, Nb, Ta, Ti, Zr, Hf, Sc, Y, La → Lu, Ac → Lr, Be, Mg, Ca, Sr, Ba, Ra, Li, Na, K, Rb, Cs, Fr, He, Ne, Ar, Kr, Xe, Rn.

This seniority order **differs** from that applied to hetero atoms used for organic polymer nomenclature guidelines.<sup>4</sup>

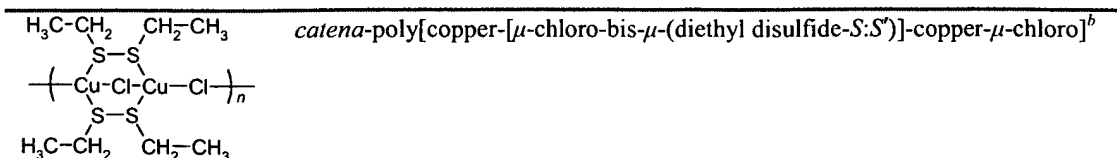
When further choice is necessary for selection of a senior subunit, preference is given, in order, to:

1. A polynuclear coordination centre, in order of decreasing number of central atoms.
2. The central atom or coordination centre with the greatest number of attached coordinating atoms, excluding coordinating atoms of bridging ligands in the polymer chain backbone.
3. The central atom or coordination centre, the name of which (including ligands and any multiplying prefixes other than bridging ligands in the polymer chain backbone) alphabetizes first.

Table 11 gives examples of application of these guidelines.

**Table 11. Examples of IUPAC Inorganic Nomenclature**

Structure	Name
$\begin{array}{c} \text{CH}_3 \\   \\ \text{---} \text{Sn} \text{---} \\   \\ \text{Ph} \end{array} \text{---}_n$	catena-poly[methylphenyltin]
$\begin{array}{cc} \text{Cl} & \text{CH}_3 \\   &   \\ \text{---} \text{Si} \text{---} & \text{Si} \text{---} \\   &   \\ \text{Cl} & \text{CH}_3 \end{array} \text{---}_n$	catena-poly[(dichlorosilicon)(dimethylsilicon)]
$\begin{array}{c} \text{NH}_3 \\   \\ \text{---} \text{Zn} \text{---} \text{Cl} \text{---} \\   \\ \text{Cl} \end{array} \text{---}_n$	catena-poly[(amminechlorozinc)-μ-chloro] <sup>a</sup>
$\begin{array}{cc} \text{H} & \text{CH}_3 \\   &   \\ \text{---} \text{B} \text{---} & \text{N} \text{---} \\   &   \\ \text{H} & \text{CH}_3 \end{array} \text{---}_n$	catena-poly[(dihydroboron)-μ-(dimethylamido)] <sup>a</sup>



<sup>a</sup>Many coordination polymers contain a mononuclear central atom with a bridging ligand. CRUs with this type of structure are named by citing (1) the central atom, together with any attached, non-bridging groups, which are cited as a prefix to the central atom; (2) the Greek letter  $\mu$ ; and (3) the bridging ligand name.

<sup>b</sup>Multiple bridging ligands between two central atoms are alphabetized. For bridging ligands, italicized element symbols (separated by a colon) that indicate the coordinating atoms are cited in the direction in which the CRU is read, i.e. left to right.

## A2.5. Nomenclature for Regular Quasi-Single-Strand Coordination Polymers

CRUs comprising backbones with one mononuclear central atom and two or more bridging ligands (alike or different), or a chelating ligand, are named as follows: (1) cite the name of the central atom, prefixed by the names of its associated non-bridging ligand(s); (2) cite the names of the bridging ligands, each prefixed by the Greek letter  $\mu$ . If there are two or more identical bridging ligands, an appropriate numerical prefix is added to indicate the number.<sup>10</sup> For polymers with identical bridging ligands, the general polymer name format is:

*catena-poly*[(associated non-bridging ligands)mononuclear central atom- $\mu$ -bridging ligand(s)]

For two or more non-identical bridging ligands, the names of the ligands are alphabetized:

*catena-poly*[(associated non-bridging ligands)mononuclear central atom- $\mu$ -bridging ligand a- $\mu$ -bridging ligand b]

Parentheses, brackets, or both, are used as needed. Table 12 shows application of these guidelines.

**Table 12. Nomenclature Examples for Quasi-Single-Strand Coordination Polymers**

Structure	Name	Structure	Name
	<i>catena-poly</i> [palladium-di- $\mu$ -chloro]		<i>catena-poly</i> [titanium-tri- $\mu$ -chloro]
	<i>catena-poly</i> [silicon-di- $\mu$ -thio]		<i>catena-poly</i> [platinum( $\mu$ -bromo- $\mu$ -chloro)]

## B. Common, Semi-Systematic, and Trivial Names Usage

Chemical nomenclature's primary goal is to identify chemical substances by their names so that scientists can communicate data about them without the need for representations of chemical structure. Systematic chemical nomenclature systems were designed specifically to enable readers to deduce chemical structures of substances from names. As discussed above, structure-based names of polymers are based on their structural features.

For many frequently used substances, however, traditional names not necessarily related to the chemical structures they represent have existed for over 40 years, and they are still used daily. These traditional names are usually referred to as common, semi-systematic, or trivial names. Provided there is no ambiguity, IUPAC allows continued use of such names, both for polymers and for polymer fragments, moieties, or subunits. IUPAC acknowledges that many common polymers have well established and frequently used semi-systematic or trivial names, and it is not intended that structure-based names should now displace them. Nevertheless, IUPAC encourages minimal use of semi-systematic or trivial polymer names in scientific communications. Examples of semi-systematic or trivial names still permitted include adipoyl, ethylene, isophthaloyl, malonyl, oxalyl, phthaloyl, succinyl, and terephthaloyl.

Table 13 gives some examples of common, semi-systematic, or trivial monomer names, together with their corresponding IUPAC systematic names. Table 14 lists some examples of common, semi-systematic, or trivial polymer names, together with their IUPAC systematic, structure-based names.

**Table 13. Selected Common Monomers: Common, Semi-Systematic, or Trivial Names vs. IUPAC Structure-Based Names**

Common, Semi-Systematic, or Trivial Names	Typical IUPAC Name <sup>a</sup>
2,2-Bis( <i>p</i> -hydroxyphenyl)propane; bisphenol A; BPA	4,4'-(1-Methylethane-1,1-diyl)diphenol
Bis(4-isocyanatophenyl)methane; 4,4'-diisocyanatodiphenylmethane; 4,4'-methylenebis(phenyl isocyanate); 4,4'-methylenediphenyl diisocyanate; MDI	Methylenedi-1,4-phenylene diisocyanate
Caprolactam	Hexano-6-lactam
1,4-Cyclohexylene diisocyanate; CHDI; 1,4-diisocyanatocyclohexane	Cyclohexane-1,4-diyl diisocyanate
1,2-Diaminocyclohexane	Cyclohexane-1,2-diamine
Diaminodiphenyl ether; DAPE; ODA; 4,4'-ODA	4,4'-Oxydianiline
1,6-Diisocyanatohexane; HDI; HMDI	Hexane-1,6-diyl diisocyanate
2,4-Diisocyanatotoluene; 2,4-TDI; 2,4-tolylene diisocyanate	4-Methyl-1,3-phenylene diisocyanate
Ethylene glycol	Ethane-1,2-diol
Hexamethylenediamine; HMD; HMDA	Hexane-1,6-diamine
Isophorone diisocyanate; IPDI	3-(Isocyanatomethyl)-3,5,5-trimethylcyclohexyl isocyanate <sup>b</sup>
Pyromellitic dianhydride; PMDA	Benzene-1,2,4,5-tetracarboxylic dianhydride

<sup>a</sup>IUPAC substance names are always unambiguous, but they are not necessarily unique; a substance may therefore have more than one IUPAC name. Some typical names are given.

The IUPAC name for IPDI is appreciably different from the uninverted CAS name 5-isocyanato-1-(isocyanatomethyl)-1,3,3-trimethylcyclohexane. This difference arises because IUPAC names IPDI as an ester of isocyanic acid, whereas CAS names it as a substituted cyclohexane (according to CAS 9CI nomenclature,<sup>11</sup> the -NCO group is not classified as a functional group).

**Table 14. Selected Common Polymers: Common, Semi-Systematic, or Trivial Names vs. IUPAC Structure-Based Names**

Common, Semi-Systematic, or Trivial Names	IUPAC Structure-Based Name
2,2-Bis(4-hydroxyphenyl)propane polycarbonate; bisphenol A polycarbonate	Poly[oxycarbonyloxy-1,4-phenylene(1-methylethane-1,1-diyl)-1,4-phenylene]
Polycaprolactam; polycaproamide; nylon 6	Poly[imino(1-oxohexane-1,6-diyl)]
Polyetherketone; PEK	Poly(oxy-1,4-phenylenecarbonyl-1,4-phenylene)
Poly(ethylene oxide), polyoxyethylene; PEO	Poly(oxyethylene)
Poly(ethylene terephthalate); PET; PETP; PETE <sup>a</sup>	Poly(oxyethyleneoxyterephthaloyl)
Poly(hexamethylene adipamide); nylon 66	Poly(iminoadipoyliminohexane-1,6-diyl)
Poly(phenylene sulfide); poly( <i>p</i> -phenylene sulfide); PPS	Poly(thio-1,4-phenylene)
Poly(tetramethylene oxide); polyoxytetramethylene; PTMO	Poly(oxybutane-1,4-diyl)

<sup>a</sup>In the United States, PETE is frequently stamped on or molded into the bottom of PET bottles for the purpose of classifying or identifying the plastic type during recycling operations.

Abbreviations and acronyms are used widely for both non-polymeric and polymeric substances, as well as for additives, modifiers, and fillers. When creating acronyms, scientists unfortunately rarely consider uniqueness. Thus, AA has been used for both acrylic acid and adipic acid, while AN has been used for both acrylonitrile and ammonium nitrate. To include a list of acronyms here would therefore serve little purpose, because new ones are created daily. IUPAC recommends that every author who writes a chemical publication should define each abbreviation used therein in a list near the beginning of the paper.<sup>13</sup> IUPAC has recommended standard abbreviations for representing polymers.<sup>14</sup> The fourth edition of the *Polymer Handbook* contains a list of commonly used abbreviations recognized by international organizations.<sup>15</sup> Publication titles should cite acronyms or abbreviations only if they are defined within the title. An example is "Preparation of poly(methyl methacrylate) (PMMA)".

### C. Polymer Class Names

Many publications (encyclopedias, handbooks, indexes, textbooks, etc.) that discuss polymer nomenclature group information on polymers under polymer class names. These classes are not mutually exclusive; some are very specific, whereas others are more generic. Table 15 lists most of the terms commonly encountered in such publications.

**Table 15. List of Commonly Encountered Polymer Class Names**

Column 1	Column 2	Column 3	Column 4
Acrylic polymers	Polyarylenes	Polyimidazoles	Polysilazanes
Alkyd resins	Polyazomethines	Polyimides	Polysiloxanes
Aminoplasts	Polybenzimidazoles	Polyimines	Polysilsesquioxanes
Coumarone-indene-resins	Polybenzothiazoles	Polyisocyanurates	Polysulfides
Epoxy resins	Polybenzoxazinones	Polyketones	Polysulfonamides
Fluoropolymers	Polybenzoxazoles	Polyolefins	Polysulfones
Phenolic resins	Polybenzyls	Polyoxadiazoles	Polythiazoles
Polyacetals	Polycarbodiimides	Polyoxides	Polythioalkylenes
Polyacetylenes	Polycarbonates	Polyoxyalkylenes	Polythioarylenes
Polyacrylics	Polycarboranes	Polyoxyarylenes	Polythioethers
Polyalkenylenes	Polycarbosilanes	Polyoxymethylenes	Polythiomethylenes
Polyalkylenes	Polycyanurates	Polyoxyphenylenes	Polythiophenylenes
Polyalkynylenes	Polydienes	Polyphenyls	Polyureas
Polyamic acids	Polyester-polyurethanes	Polyphosphazenes	Polyurethanes
Polyamides	Polyesters	Polypyrroles	Polyvinyl acetals
Polyamines	Polyetheretherketones	Polypyrrones	Polyvinyl butyrals
Polyanhydrides	Polyether-polyurethanes	Polyquinolines	Polyvinyl formals
Polyarylenealkenylenes	Polyethers	Polyquinoxalines	Vinyl polymers
Polyarylenealkylenes	Polyhydrazides	Polysilanes	

### D. References and Notes

1. IUPAC recommends that subscripts "n" and "x", denoting multiplicities of polymeric sequences, should be italicized, or (in the absence of italics), underlined.
2. Unfortunately the word "copolymer" is used also to indicate a polymer containing two types of monomer. Use of the word "bipolymer" for a polymer containing two types of monomer would be in accord with use of "terpolymer" for a polymer containing three types of monomer, "quaterpolymer" (rather than tetrapolymer) for a polymer containing four types of monomer, etc.
3. IUPAC: "Source-Based Nomenclature for Non-Linear Macromolecules and Macromolecular Assemblies (Recommendations 1997)." *Pure Appl. Chem.*, **1997**, *69*, 2511-2521.
4. IUPAC: "Nomenclature of Regular Single-Strand Organic Polymers (Recommendations 1975)." *Pure Appl. Chem.*, **1976**, *48*, 373-385; reprinted as chapter 5 in ref. 18.



5. Chemical Abstracts Service, 2540 Olentangy River Road, P.O. Box 3012, Columbus, OH 43210: *CA Index Guide*, Appendix IV: Chemical Substance Index Names (© 1999). Section 222 – Description of Polymer Indexing Rules.
  6. IUPAC: "Nomenclature of Regular Double-Strand (Ladder and Spiro) Organic Polymers (Recommendations 1993)." *Pure Appl. Chem.*, **1993**, *65*, 1561-1580.
  7. Concerning ring seniority, there is one difference between the IUPAC recommendations and the CAS principles: everything else being equal, IUPAC prefers a fused ring system to a spiro ring system, whereas CAS prefers a spiro ring system to a fused ring system. The reason for this one difference is unknown.
  8. This name corresponds strictly to a polymer composed entirely of -O-CH(Me)-CH<sub>2</sub>- units. For this polymer, frequently called simply "polyoxypropylene", CAS uses a different approach to registration; in recognition of the occurrence within the polymer of both -O-CH(Me)-CH<sub>2</sub>- and -O-CH<sub>2</sub>-CH(Me)- units, CAS names it poly[oxy(methyl-1,2-ethanediyl)], and the accompanying structure reflects the unspecified position of the methyl group. For the subunit -CH<sub>2</sub>-CH<sub>2</sub>-, CAS uses 1,2-ethanediyl, whereas IUPAC permits ethane-1,2-diyl but still prefers ethylene.
  9. IUPAC: "Structure-Based Nomenclature for Irregular Single-Strand Organic Polymers (Recommendations 1994)." *Pure Appl. Chem.*, **1994**, *66*, 872-889.
  10. IUPAC: "Nomenclature for Regular Single-Strand and Quasi Single-Strand Inorganic and Coordination Polymers (Recommendations 1984)." *Pure Appl. Chem.*, **1985**, *57*, 149-168; reprinted as chapter 6 in ref. 18.
  11. The so-called 9CI nomenclature was introduced by CAS at the beginning of the Ninth Collective Index period (1972). The reasons for its introduction were delineated in the Ninth Collective *CA Index Guide* and in a journal article (see ref. 12).
  12. Donaldson, N.; Powell, W. H.; Rowlett Jr., R. J.; White, R. W.; Yorka, K. V. "Chemical Abstracts Index Names for Chemical Substances in the Ninth Collective Period (1972-1976)." *J. Chem. Doc.*, **1974**, *14*, 3-15.
  13. IUPAC: "Use of Abbreviations in the Chemical Literature (Recommendations 1979)." *Pure Appl. Chem.*, **1980**, *52*, 2229-2232.
  14. IUPAC: "Use of Abbreviations for Names of Polymeric Substances (Recommendations 1986)." *Pure Appl. Chem.*, **1987**, *59*, 691-693; reprinted as chapter 9 in ref. 18.
  15. Elias, H.-G. "Abbreviations for Thermoplastics, Thermosets, Fibers, Elastomers, and Additives," Brandrup, J.; Immergut, E. H.; Grulke E. A. (eds.): *Polymer Handbook*, 4th ed., VII:1-24, John Wiley & Sons, Inc., New York, 1998.
- Six additional references, not cited in the text of this document, also discuss polymer nomenclature:
16. Wilks, E. S. "Macromolecular Nomenclature Note No. 17; Whither Nomenclature?" *Polym. Prepr.*, **1999**, *40*(2), 6-11. This article lists all significant documents on polymer nomenclature published in the last 50 years.
  17. IUPAC: "Source-Based Nomenclature for Copolymers (Recommendations 1985)." *Pure Appl. Chem.*, **1985**, *57*, 1427-1440; reprinted as chapter 7 in ref. 16.
  18. IUPAC: *Compendium of Macromolecular Nomenclature* ("Purple Book"), Metanomski, W. V. (ed.), Blackwell Sci. Publ., Oxford 1991. The book is out of print; an electronic version is available at website <http://www.iupac.org/divisions/IV/index.html>.
  19. American Chemical Society: "A Structure-Based Nomenclature for Linear Polymers." *Macromolecules* **1968**, *1*, 193-198.
  20. American Chemical Society: "A Structure-Based Nomenclature for Linear Polymers." *Polym. Prepr.* **1967**, *8*(2), e-r.
  21. IUPAC: "Report on Nomenclature in the Field of Macromolecules (1951): Section VII – Linear High Polymers." *J. Polym. Sci.* **1952**, *8*, 257-277.